Net Ionic Equations Roadmap

- Being able to classify the reaction type is the key to writing the net ionic equation.
- Reaction Types (Watch for this):
  - Precipitation (ions and solubility)
  - Acid-Base (ions and water# form)
  - Gas Forming (gas forms)
  - Redox (oxidation numbers change)
- Net ionic equations show key chemistry

Syllabus Learning Outcomes : 8, 9, and 10

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2

Soluble salts form aqueous ions when dissolved in water

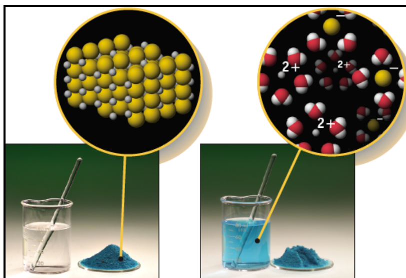
water + salt → aqueous solution

$CuCl_2$ (s) → Cu^{2+}(aq) + $2Cl^-$(aq)

soluble salt

* Soluble ions form in water solution

3



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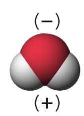
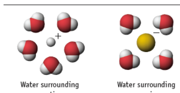




An Ionic Compound, $CuCl_2$, in Water

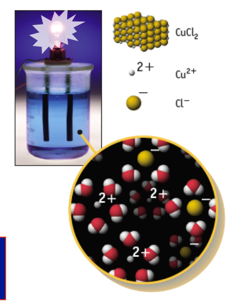
* Forms ions in solution

4

Ions Conduct Electricity

Solutions with ions are called ELECTROLYTES

HCl, NaOH, $CuCl_2$, and NaCl are strong electrolytes. They dissociate completely (or nearly so) into ions.



* Dissociated ions form in solution that conduct electricity. Water and solid salt do not conduct electricity.

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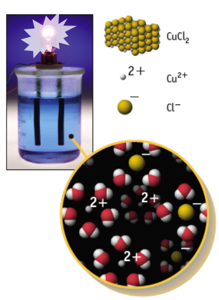
Strong Electrolytes Are:

1) Ionic compounds, strong acids or strong bases (not molecular compounds, weak acids or weak bases)

2) Soluble in water (not insoluble or slightly soluble)



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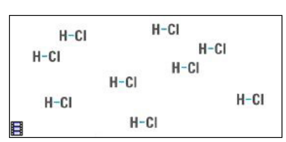
Aqueous Solutions

HCl, $CuCl_2$, and NaCl are strong electrolytes. They dissociate completely (or nearly so) into ions.



* Form ions in solution

Aqueous Solutions

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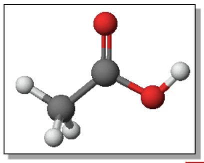
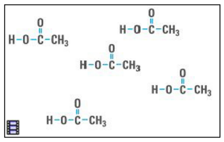
Acetic acid ionizes only to a small extent, so it is a **weak electrolyte.**

$CH_3CO_2H(aq) \dashrightarrow CH_3CO_2^-(aq) + H^+(aq)$





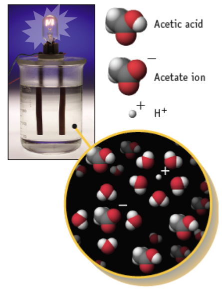
* Forms primarily molecules in solution

Weak Electrolytes Form Few Ions

8

Acetic acid is a **weak electrolyte.**

$CH_3CO_2H(aq) \rightleftarrows CH_3CO_2^-(aq) + H^+(aq)$



* Mostly molecules in solution, not ions

Nonelectrolytes Form No Ions

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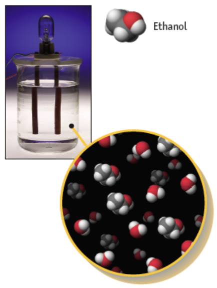
Some compounds dissolve in water

Examples include:
- sugar
- ethanol
- ethylene glycol



Some compounds don't dissolve much in water

Examples include:
- $CaCO_3$
- $AgCl$
- Hg_2SO_4

Determine Water Solubility of Ionic Compounds

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Soluble Ionic Compounds

1. All compounds of the alkali metals (Group IA) are soluble.
2. All salts containing NH_4^+, NO_3^-, ClO_4^-, and $C_2H_3O_2^-$ are soluble.
3. All chlorides (Cl^-), bromides (Br^-), and iodides (I^-) are soluble, *except* those of Ag^+, Pb^{2+}, and Hg_2^{2+} (note the subscript "2").
4. All sulfates are soluble, *except* those of Pb^{2+}, Ca^{2+}, Sr^{2+}, Hg_2^{2+}, and Ba^{2+}.

Insoluble Ionic Compounds

5. All hydroxides (OH^-) and metal oxides (containing O^{2-}) are insoluble, *except* those of Group IA and Ca^{2+}, Sr^{2+}, and Ba^{2+}. When metal oxides do dissolve, they give hydroxides (their solutions do not contain O^{2-} ions). For example,

$$Na_2O(s) + H_2O \rightarrow 2\ NaOH(aq)$$

6. All compounds that contain PO_4^{3-}, CO_3^{2-}, SO_3^{2-}, and S^{2-} are insoluble, *except* those of Group IA and NH_4^+

•Soluble ionic compounds form ions in solution and are electrolytes

•Insoluble ionic compounds form no ions in solution and are nonelectrolytes

Solubility rules are given

Practice: $Mg(OH)_2$

Water Solubility of Ionic Compounds

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If one ion from the "Soluble Compound." list is present in a compound, the compound is water soluble.

SOLUBLE COMPOUNDS	EXCEPTIONS
Almost all salts of Na^+, K^+, NH_4^+	
Salts of nitrate, NO_3^-; chlorate, ClO_3^-; perchlorate, ClO_4^-; acetate, $CH_3CO_2^-$	
Almost all salts of Cl^-, Br^-, I^-	Halides of Ag^+, Hg_2^{2+}, Pb^{2+}
Compounds containing F^-	Fluorides of Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}
Salts of sulfate, SO_4^{2-}	Sulfates of Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}

INSOLUBLE COMPOUNDS	EXCEPTIONS
Most salts of carbonate, CO_3^{2-}; phosphate, PO_4^{3-}; oxalate, $C_2O_4^{2-}$; chromate, CrO_4^{2-}	Salts of NH_4^+ and the alkali metal cations
Most metal sulfides, S^{2-}	
Most metal hydroxides and oxides	$Ba(OH)_2$ is soluble

•Soluble ionic compounds form ions in solution and are electrolytes

•Insoluble ionic compounds form no ions in solution and are nonelectrolytes

Given

Water Solubility of Ionic Compounds

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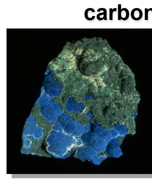
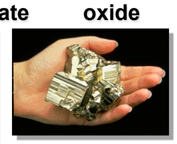
Common minerals are often formed with anions that lead to insolubility:

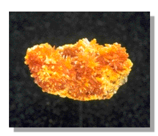
sulfide fluoride
carbonate oxide



Azurite, a copper carbonate



Iron pyrite, a sulfide



Orpiment, arsenic sulfide

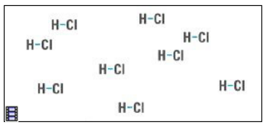
* Mostly, no ions are in solution

Acids Form H_3O^+ in Water

$HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$

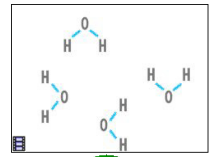
$HCl(aq) + H_2O(\ell) \rightarrow H_3O^+ (aq) + Cl^- (aq)$

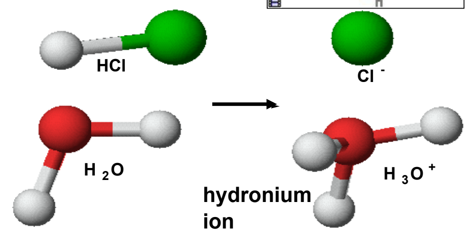
HCl is a strong acid →



Write formulas of acids with H at the beginning (or at the end)

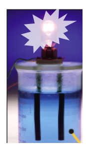
The Nature of Acids



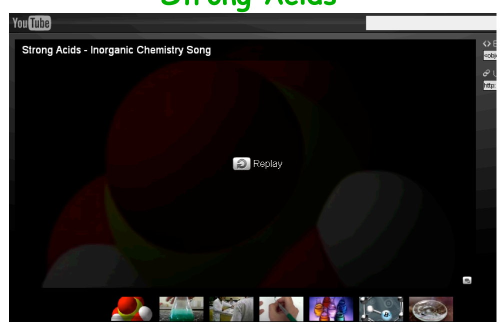


Memorize the 6 Strong Acids

HCl	hydrochloric acid
HBr	hydrobromic acid
HI	hydroiodic acid
H_2SO_4	sulfuric acid
$HClO_4$	perchloric acid
HNO_3	nitric acid



Strong Acids



Strong Acids: Quiz

Which of the following is NOT a strong acid?

Poll Everywhere

To vote: Text a CODE to 99503

HCl	105288
HBr	105289
H2SO4	105290
HF	105291
HNO3	105292

All Other Acids Are Weak

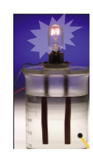
CH_3CO_2H acetic acid, vinegar (CH_3COOH, HOAc, $HC_2H_3O_2$)

H_2CO_3 carbonic acid

H_3PO_4 phosphoric acid

HF hydrofluoric acid

And many more…



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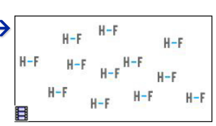

* Weak acids form primarily molecules (not ions) in solution so they are weak electrolytes or nonelectrolytes in water

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Nonmetal Oxides Can Be Acids

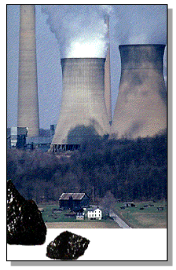
- Burning fuel containing C

$CO_2(aq) + H_2O(\ell) \rightarrow H_2CO_3(aq)$

- Burning fuel containing S

$SO_3(aq) + H_2O(\ell) \rightarrow H_2SO_4(aq)$

Are these acids strong or weak?



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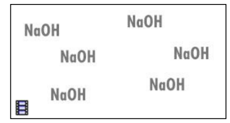
Bases form OH^- in Water

$NaOH(aq) \rightarrow Na^+(aq) + OH^-(aq)$

NaOH is a strong base →



Write formulas of bases that contain OH with the OH at the end

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Table 4.1 Common Strong Acids and Strong Bases

Acids		Bases	
Binary Hydrogen Compounds	Oxoacids	Group 1A hydroxides	Group 2A hydroxides
HCl	HNO_3	LiOH	$Mg(OH)_2$
HBr	H_2SO_4[a]	NaOH	$Ca(OH)_2$
HI	$HClO_4$	KOH	$Sr(OH)_2$
		RbOH	$Ba(OH)_2$
		CsOH	

[a] H_2SO_4 is a strong acid in its first ionization step but weak in its second ionization step.

Know the strong acids & bases!

Less Common

Less Soluble

Soluble strong acids and bases form ions in solution

Weak acids, weak bases and insolubles form few ions in solution

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Memorize the 4 Strong Bases

LiOH — Lithium hydroxide

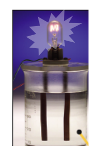
NaOH — Sodium hydroxide

KOH — Potassium hydroxide

$Ba(OH)_2$ — Barium hydroxide

Other bases are:

- Weak — NH_3
- Not very soluble — $Ca(OH)_2$
- Not common — CsOH



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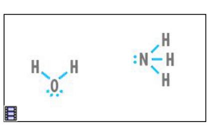
Ammonia, NH_3
An Important Weak Base

$NH_3(g) + H_2O(\ell) \rightleftarrows NH_4^+(aq) + OH^-(aq)$

→



When $NH_4OH(aq)$ is produced, $NH_3(g)$ forms.

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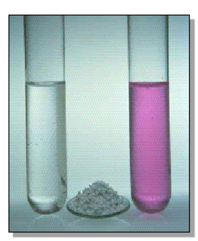
Most Metal Oxides are Bases

$CaO(s) + H_2O(\ell) \rightarrow Ca(OH)_2(aq)$



•CaO in water.

•Pink indicator shows solution is basic.

Writing Net Ionic Equations

- Write the <u>total ionic equation</u> by dissociating species that form ions (Keep solids, liquids, gases, weak acids, and weak bases together as molecules)
- Cancel ions (spectator ions) if they are the same on both sides of a reaction to give the <u>net ionic equation</u>.

Example Net Ionic Equation

$Mg(s) + 2HCl(aq) \rightarrow H_2(g) + MgCl_2(aq)$

Step 1) Dissociate into ions (total ionic equation)

$Mg(s) + 2H^+(aq) + 2Cl^-(aq) \rightarrow H_2(g) + Mg^{2+}(aq) + 2Cl^-(aq)$

Step 2) Cancel spectator ions (net ionic equation)

$Mg(s) + 2H^+(aq) \rightarrow H_2(g) + Mg^{2+}(aq)$

Cl^- ions are **SPECTATOR IONS**
Could have used another anion, NO_3^-.

Net Ionic Equations

$Mg(s) + 2\ HCl(aq)$
$\text{-->}\ H_2(g) + MgCl_2(aq)$

$Mg(s) + 2\ H^+(aq) + 2\ Cl^-(aq)$
$\text{--->}\ H_2(g) + Mg^{2+}(aq) + 2\ Cl^-(aq)$

We leave the spectator ions out —
$Mg(s) + 2\ H^+(aq)\ \text{--->}\ H_2(g) + Mg^{2+}(aq)$

to give the **NET IONIC EQUATION**

Note that gases (H_2) and metals Mg(s) are not ions

Chemical Reactions in Water

We will look at
EXCHANGE REACTIONS

$Pb(NO_3)_2(aq) + 2\ KI(aq)$
$\text{---->}\ PbI_2(s) + 2\ KNO_3(aq)$

$AX + BY \longrightarrow AY + BX$

The anions exchange places between cations.

Net Ionic Equations Roadmap

- Being able to classify the <u>reaction type</u> is the key to writing the net ionic equation.
- Reaction Types (Watch for this):
  - Precipitation (ions and solubility)
  - Acid-Base (ions and water# forms)
  - Gas Forming (gas forms)
  - Redox (oxidation numbers change)
- Net ionic equations show key chemistry

Types of Reactions

- Acid-Base or Neutralization
- Precipitation
- Gas forming
- (Redox)
- No reaction

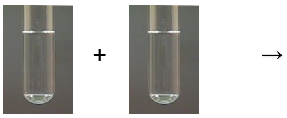
Recognize Precipitation Reactions

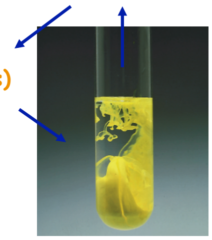
$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow 2KNO_3(aq) + PbI_2(s)$

- Driving force is forming a precipitate

Net ionic equation

$Pb^{2+}(aq) + 2I^-(aq) \rightarrow PbI_2(s)$





Recognize Acid-Base Reactions

$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(\ell)$

Driving force is forming water

Net ionic equation

$OH^-(aq) + H^+(aq) \rightarrow H_2O(\ell)$

This net ionic equation applies to STRONG acids and STRONG bases because weak acids and weak bases stay as molecules.

Recognize Acid-Base Reactions

- Also called Neutralizations
- Other product of Acid-Base reaction is a Salt, MX.

$HX + MOH \text{ ---> } MX + H_2O$

M^{n+} comes from base & X^{n-} comes from acid

This is one way to make compounds!

Gas-Forming Reactions

This is primarily the chemistry of metal carbonates (MCO_3).

CO_2 and water ---> H_2CO_3

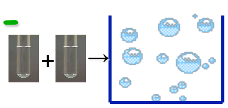
$H_2CO_3(aq) + Ca^{2+}$ --->

$2\ H^+(aq) + CaCO_3(s)$ (limestone)

Adding acid reverses this reaction.

MCO_3 + acid ---> CO_2 (g) + salt

Recognize Gas-Forming Reactions



$CaCO_3(s) + H_2SO_4(aq) \rightarrow CaSO_4(s) + H_2CO_3(aq)$

Carbonic acid is unstable and forms CO_2 (g) & H_2O (ℓ)

$H_2CO_3(aq) \rightarrow CO_2(g) + H_2O(\ell)$

When $NH_4OH(aq)$ is produced in a chemical reaction ($NaOH + NH_4Cl$), $NH_3(g)$ forms.

Table 5.3 Gas-Forming Reactions

*	**Metal carbonate or bicarbonate + acid $\longrightarrow$ metal salt + $CO_2(g) + H_2O(\ell)$**
	$Na_2CO_3(aq) + 2\ HCl(aq) \longrightarrow 2\ NaCl(aq) + CO_2(g) + H_2O(\ell)$
	Metal sulfide + acid $\longrightarrow$ metal salt + $H_2S(g)$
	$Na_2S(aq) + 2\ HCl(aq) \longrightarrow 2\ NaCl(aq) + H_2S(g)$
	Metal sulfite + acid $\longrightarrow$ metal salt + $SO_2(g) + H_2O(\ell)$
	$Na_2SO_3(aq) + 2\ HCl(aq) \longrightarrow 2\ NaCl(aq) + SO_2(g) + H_2O(\ell)$
	Ammonium salt + strong base $\longrightarrow$ metal salt + $NH_3(g) + H_2O(\ell)$
*	$NH_4Cl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + NH_3(g) + H_2O(\ell)$

Active metal + acid $\rightarrow$ metal salt + H_2 (g)

$Fe (s) + HCl \rightarrow FeCl_3 + H_2(g)$

+ others

Ions – Review for Net Ionic Equations

- Soluble ionic compounds provide lots of ions in solution
- Acids provide H^+ ions in solution.
  - Strong acids provide lots of ions in solution (HCl, HBr, HI, HNO_3, $HClO_4$, H_2SO_4)
  - Weak acids provide few ions (H_3PO_4, H_2CO_3, …).
- Bases provide OH^- ions in solution.
  - Strong bases provide lots of ions in solution (LiOH, NaOH, KOH)
  - Weak bases provide few ions in solution (NH_3, $Ca(OH)_2$)
- Some soluble compounds like sugar, ethanol, ethylene glycol provide no ions in solution

Classifying Reactions

Precipitation Reaction

$Al_2(SO_4)_3(aq) + 3\ Ba(NO_3)_2(aq) \rightarrow 2\ Al(NO_3)_3(aq) + 3\ BaSO_4(s)$

Net Ionic Equation

$Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4(s)$

Al^{3+} and NO_3^- are spectator ions

Gas Forming

$Fe(s) + 2\ HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$

Net Ionic Equation

$Fe(s) + 2\ H^+(aq) \rightarrow Fe^{2+}(aq) + H_2(g)$

Cl^- is spectator ion

Classifying Reactions

Strong Acid / Strong Base

$H_2SO_4(aq) + 2\ KOH(aq) \rightarrow K_2SO_4(aq) + 2\ H_2O(l)$

Net Ionic Equation

$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

K^+ and SO_4^{2-} are spectator ions

Strong acid / Weak Base

$HCl\ (aq) + NH_3\ (aq) \rightarrow NH_4Cl\ (aq)$

Cl^- is spectator ion

Net Ionic Equation

$H^+\ (aq) + NH_3\ (aq) \rightarrow NH_4^+\ (aq)$

Classifying Reactions

Weak acid / Strong Base

$CH_3CO_2H\ (aq) + NaOH\ (aq) \rightarrow NaCH_3CO_2\ (aq) + H_2O\ (l)$

Net Ionic Equation

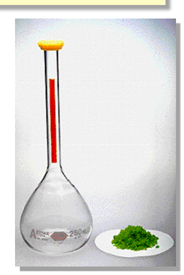
$CH_3CO_2H\ (aq) + OH^-\ (aq) \rightarrow CH_3CO_2^-\ (aq) + H_2O\ (l)$

Na^+ is spectator ion

Quantitative Aspects of Reactions in Solution

Terminology for Solutions

- SOLVENT - does the dissolving.
- SOLUTE - the other solution component.



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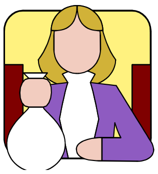
Molarity Is A Unit of Concentration

$$\text{Molarity (M)} = \frac{\text{moles solute}}{\text{1 liter of solution}}$$



The solution includes the solute and the solvent

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Units of Molarity Are

$$2.0 \text{ M HCl} = \frac{\text{2.0 moles HCl}}{\text{1 L HCl solution}}$$

[HCl] = 2.0M

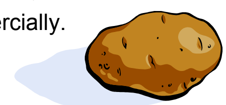
$$6.0 \text{ M HCl} = \frac{\text{6.0 moles HCl}}{\text{1 L HCl solution}}$$

[HCl] = 6.0M

45

Molarity Calculation

NaOH is used to open stopped sinks, to treat cellulose in the making of nylon, and to remove potato peels commercially.



If 4.0 g NaOH are used to make 500. mL of NaOH solution, what is the molarity (M) of the solution?

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Calculating Molarity

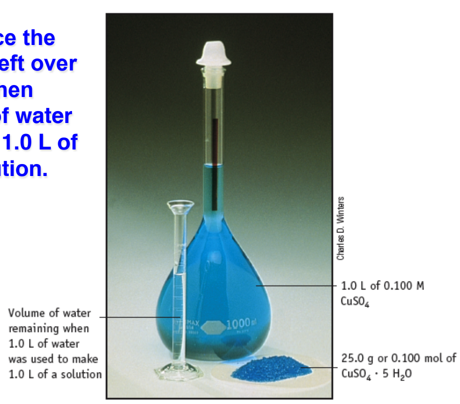
1) $4.0 \text{ g NaOH} \times \frac{\text{1 mole NaOH}}{\text{40.0 g NaOH}} = 0.10 \text{ mole NaOH}$

2) $500. \text{ mL} \times \frac{\text{1 L}}{\text{1000 mL}} = 0.500 \text{ L}$

3) $\frac{\text{0.10 mole NaOH}}{\text{0.500 L}} = \frac{\text{0.20 mole NaOH}}{\text{1 L}}$

[NaOH] = 0.20M

Notice the water left over when 1.0 L of water makes 1.0 L of solution.



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How to Prepare a Solution

PROBLEM: Dissolve 5.00 g of $NiCl_2 \cdot 6\ H_2O$ in enough water to make 250 mL of solution. Calculate molarity.

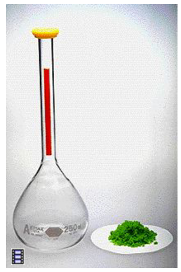
Step 1: Calculate moles of $NiCl_2 \cdot 6H_2O$

$$5.00\ \text{g} \cdot \frac{1\ \text{mol}}{237.7\ \text{g}} = 0.0210\ \text{mol}$$

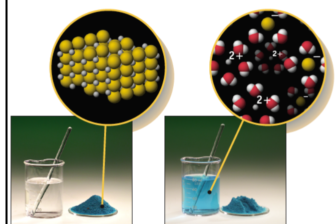
Step 2: Calculate molarity

$$\frac{0.0210\ \text{mol}}{0.250\ \text{L}} = 0.0841\ \text{M}$$

$[NiCl_2] = 0.0841\ \text{M}$



Determine Concentrations of Ions in a 0.30M $CuCl_2$ Solution



$CuCl_2(aq) \rightarrow$
$Cu^{2+}(aq) + 2\ Cl^-(aq)$

If $[CuCl_2] = 0.30$ M, then

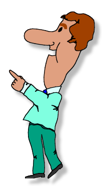
$[Cu^{2+}] = 0.30$ M

$[Cl^-] = 2 \times 0.30$ M

Problem: What mass of oxalic acid, $H_2C_2O_4$, is required to make 250. mL of a 0.0500 M solution?

M = moles/V

so **moles = M•V**

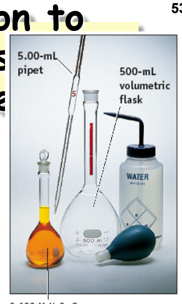


Problem: What mass of oxalic acid, $H_2C_2O_4$, is required to make 250. mL of a 0.0500 M solution?

Step 1: Calculate moles of acid.
(0.250 L)(0.0500 mol/L) = 0.0125 mol

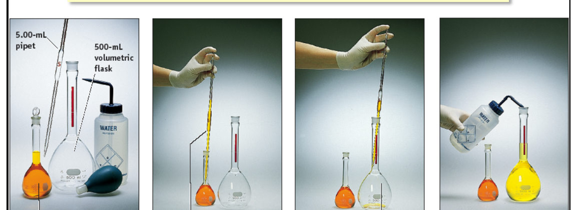
Step 2: Calculate mass of acid.
(0.0125 mol)(90.00 g/mol) = 1.13 g

Dilute a solution to give one that is … concentrate…



0.100 M $K_2Cr_2O_7$

Preparing a Solution by Dilution



0.100 M $K_2Cr_2O_7$

Use a 5.00-mL pipet to withdraw 5.00 mL of 0.100 M $K_2Cr_2O_7$ solution.

Add the 5.00-mL sample of 0.100 M $K_2Cr_2O_7$ solution to a 500-mL volumetric flask.

Fill the flask to the mark with distilled water to give 0.00100 M $K_2Cr_2O_7$ solution.

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PROBLEM: You have 50.0 mL of 3.0 M NaOH and you want 0.50 M NaOH. What do you do?

Add water to the 3.0 M solution to lower its concentration to 0.50 M

Dilute the solution!

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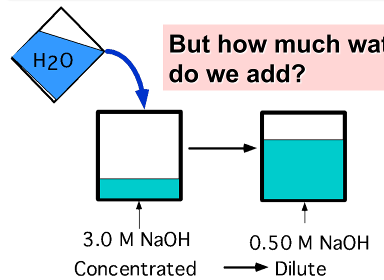
PROBLEM: You have 50.0 mL of 3.0 M NaOH and you want 0.50 M NaOH. What do you do?

But how much water do we add?



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PROBLEM: You have 50.0 mL of 3.0 M NaOH and you want 0.50 M NaOH. What do you do?

How much water is added? What is the final volume?

The important point is that --->

moles of NaOH in ORIGINAL solution = moles of NaOH in FINAL solution

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PROBLEM: You have 50.0 mL of 3.0 M NaOH and you want 0.50 M NaOH. What do you do?

Amount of NaOH in original solution =

$M \bullet V$ =

(0.050 L)(3.0 mol/L) = 0.15 mol NaOH

Amount of NaOH in final solution must also = 0.15 mol NaOH

Volume of final solution =

(0.15 mol NaOH)(1 L/0.50 mol) = 0.30 L

or 300 mL

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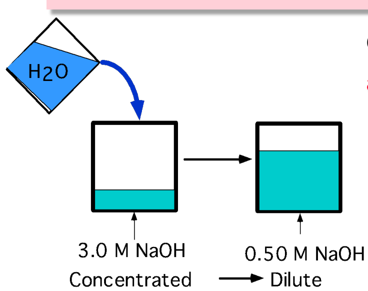
PROBLEM: You have 50.0 mL of 3.0 M NaOH and you want 0.50 M NaOH. What do you do?



Conclusion:

add 250 mL of water to 50.0 mL of 3.0 M NaOH to make 300 mL of 0.50 M NaOH.

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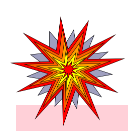
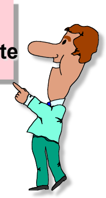
Preparing Solutions by Dilution



A shortcut

$$M_{conc} \bullet V_{conc} = M_{dilute} \bullet V_{dilute}$$



It will be helpful to be able to calculate molarity both ways for Chem II

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PROBLEM: You have 50.0 mL of 3.0 M NaOH and you want 0.50 M NaOH. What do you do?

M_{conc} = 3.0M
V_{conc} = 0.0500L

M_{dilute} = 0.50M
V_{dilute} = ?

$M_{conc} * V_{conc} = C_{dilute} * V_{dilute}$

$3.0M * 0.0500L = 0.50M * V_{dilute}$

V_{dilute} = 0.3 L,

To the 0.050L NaOH, add 0.250L of water

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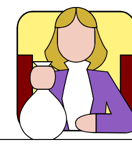
Concentration of Solute

A concentration that expresses the moles of solute in 1 L of solution

Molarity (M) = $\frac{\text{moles of solute}}{\text{1 liter solution}}$

Concentration (M) = […]



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End